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Diurnal Lightning Distributions as Observed by the Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS)

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ABSTRACT: Data obtained from the Optical Transient Detector (April 1995 to March 2000) and the Lightning Imaging Sensor (December 1997 to December 2005) satellites (70° and 35° inclination low earth orbits, respectively) are used to statistically determine the number of flashes in the annual and seasonal diurnal cycle as a function of local and universal time. The data are further subdivided by season, land versus ocean, northern versus southern hemisphere, and other spatial (e.g., continents) and temporal (e.g., time of peak diurnal amplitude) categories. The data include corrections for detection efficiency and instrument view time. Continental results display strong diurnal variation, with a lightning peak in the late afternoon and a minimum in late morning. In regions of the world dominated by large mesoscale convective systems the peak in the diurnal curve shifts toward late evening or early morning hours. The maximum diurnal flash rate occurs in June – August, corresponding to the Northern Hemisphere summer, while the minimum occurs in December– February. Summer lightning dominates over winter activity and springtime lightning dominates over autumn activity at most continental locations. This latter behavior occurs especially strongly over the Amazon region in South America in September – November. Oceanic lightning activity in winter and autumn tends to exceed that in summer and spring. Global lightning is well correlated in phase but not in amplitude with the Carnegie curve. The diurnal flash rate varies about ±35% about the mean, while the Carnegie curve varies around ±15%.

1. INTRODUCTION

Since April 1995, first the Optical Transient Detector (OTD) and then the Lightning Imaging Sensor (LIS) have monitored lightning activity around the globe with a high detection efficiency from low Earth orbit. More than eleven years of observations from these sensors provide quantitative statistics on worldwide lightning occurrence when averaged over this time period. An earlier study [Christian et al., 2003] described the frequency and distribution of the global lightning activity. In this paper, we present results on the diurnal lightning activity derived from the combined OTD/LIS observations during 11.5 years in orbit. In addition, the paper re-examines the global electric circuit implications of these observations.

2. MEASUREMENTS

The OTD, launched into a 70° inclination (detects to ~±75° latitude), 735 km altitude orbit on the MicroLab-1 satellite (later renamed OV-1), collected observations for a 5-year period from April 1995 until March 2000. The LIS, launched in November 1997 on-board the Tropical Rainfall Measuring Mission (TRMM) satellite into a 35° inclination (detects to ~±39° latitude), 350 km altitude orbit, remains operational. Given the orbital trajectories of these satellites, the complete diurnal cycle is sampled over 55 (49) days for OTD (LIS). When averaged over a seasonal or annual time period, sufficient data is available to calculate the diurnal lightning distribution. Gridded flash products (2.5° x 2.5° resolution bins) are used for the analyses in this paper.

3. RESULTS

3.1 Annual diurnal cycle

The global annual diurnal cycle (Figure 1), derived from the combined OTD/LIS data for both universal (UTC) and local time (LT), shows the variation from the entire world, the continental regions, the oceans, and the subset of the world observed by LIS alone. All continents have a strong diurnal variation, with the lightning

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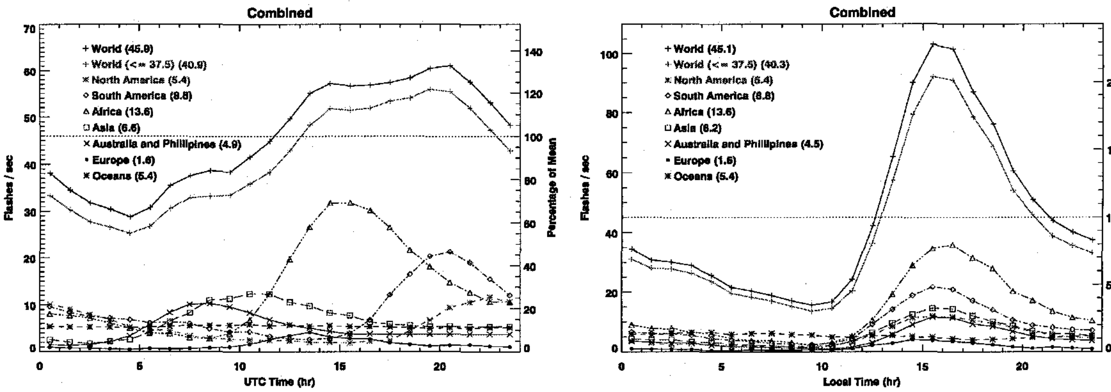

Figure 1. Annual diurnal flash rate derived from the combined OTD/LIS data

activity peaking in the late afternoon between 1500 to 1700 LT. The minimum local lightning activity occurs in the late morning hours between 0900 to 1100 LT. In regions of the world dominated by large mesoscale convective systems [Zipser et al., 2006], the peak in the diurnal curve shifts toward late evening or early morning hours. Oceanic lightning exhibits minimal diurnal behavior, but morning hours are slightly enhanced over afternoon. On an annual basis, LIS alone misses about 10% of the lightning in the Northern Hemisphere and 1.5% in the Southern Hemisphere, but this is seasonally dependent (most missed during N. H. summer).

3.2 Seasonal diurnal cycle

Figure 2 compares the seasonal diurnal flash rates for the world (UTC and LT), while Figure 3 provides details of how different global regions contribute to each of the seasonal diurnal curves. The maximum diurnal flash rate occurs in June – August (JJA) corresponding to the Northern Hemisphere summer, when greatly enhanced lightning activity from the North American and Asia continents combine with the relatively steady contribution (across all seasons) from Africa. The September – November (SON) period exceeds March – May (MAM), due especially to the enhanced South American contribution that occurs during SON. Throughout all seasons, Africa provides the largest single contribution to the diurnal cycle (and, Africa with its land-mass centered about the equator, exhibits a small semi-annual signal in the flash rate). Table 1 summarizes the annual and seasonal mean flash rates for the world and other regions. Noteworthy results are in blue italicised text.

4. DISCUSSION

4.1 Seasonal Variability

Analyses of seasonal lightning distribution maps yield additional insights pertinent to a better understanding of the diurnal behavior. Difference maps (Figure 4), derived by taking the difference between distribution maps of opposite seasons (i.e., JJA-DJF, DJF-JJA, MAM-SON, and SON-MAM) and plotting only the positive values, show in which season (summer versus winter, spring versus fall) a location on the Earth has greater lightning occurrence. Over land, not unexpectantly, summer lightning dominates over winter activity, with lightning in Northern Hemisphere summer (JJA) greatly exceeding that found in Southern Hemisphere summer (DJF) due to its much greater land mass. This is also reflected in the results in Figures 2 and 3. However, the

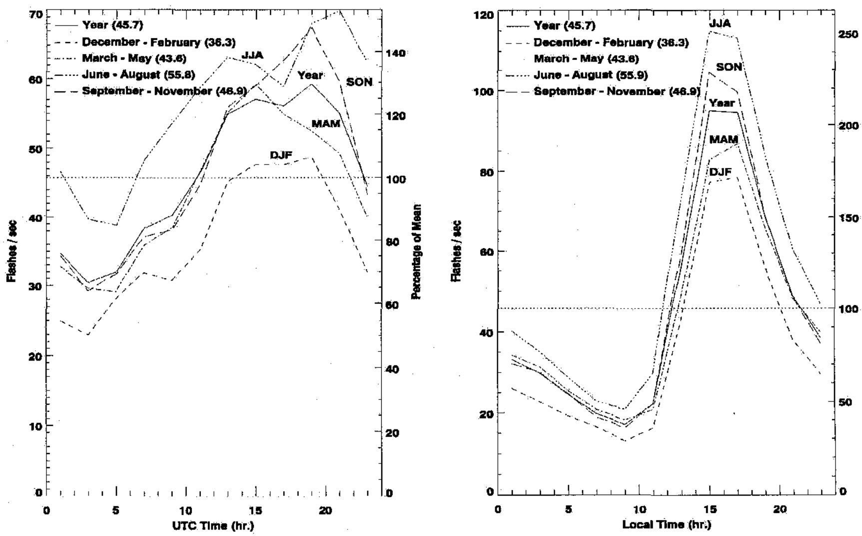

Figure 2. Seasonal diurnal flash rate derived from the combined OTD/LIS data

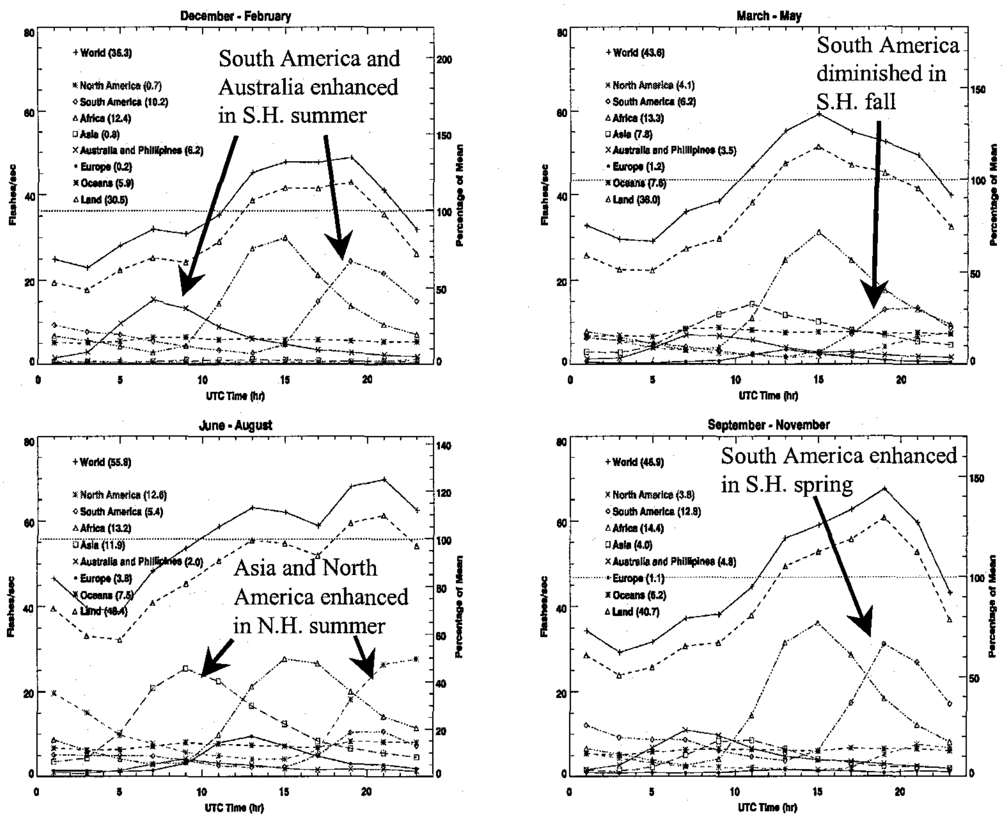

Figure 3. Seasonal diurnal flash rates for world, land, ocean, and continents

difference analysis also reveals that springtime lightning dominates over the autumn activity at most locations, a result not expected a priori. This latter behavior occurs strongly over the Amazon region in South America, perhaps as a manifestation of the "green ocean" effect [Williams et al., 2002] diminishing lightning activity in the South America fall (MAM). In fact, similar behavior occurs, albeit to lesser degree, at many land-based locations around the Earth. In contrast to the land, the difference analyses show that over oceanic regions, lightning activity in the winter and autumn months tends to exceed that in summer and spring, respectively.

4.2 Comparison with Carnegie curve

One of the goals of improved space-based lightning measurements is to better understand the processes involved in sustaining the global electric circuit. At the early part of last century, researchers hypothesized that thunderstorms were responsible for the currents that circulate in the Earth's atmosphere between the highly conductive ionosphere and the surface of the Earth [Wilson, 1920]. This discovery eventually led to the modern concept of the global electric circuit. The variation in the global diurnal lightning frequency (Figure 1) reflects the integrated contribution of thunderstorms from the major lightning producing centers of the world – Africa, the Americas, and Asia and Australia – in good agreement with the classic work by Whipple and Scrase [1936]

Table 1: Annual and seasonal lightning (flashes/s) for world, continents, oceans, land, and the LIS orbital extent.

Region	Year	Year%	SON	SON%	DJF	DJF%	MAM	MAM%	JJA	JJA%	Season Order	Local Season Order
World	45.1	100.0	46.9	100.0	36.3	100.0	43.6	100.0	55.9	100.0	JJA,SON,MAM,DJF	
Africa	13.6	30.2	14.4	30.7	12.4	34.2	13.3	30.5	13.2	23.6	*SON,MAM,JJA,DJF*	
South America	8.8	19.5	12.8	27.3	10.2	28.1	6.2	14.2	5.5	9.8	*SON,DJF,MAM,JJA*	*Spring,Summer,Fall,Winter*
Asia	6.2	13.7	4.0	8.5	0.8	2.2	7.8	17.9	11.9	21.3	JJA,MAM,SON,DJF	Summer,Spring,Fall,Winter
North America	5.4	12.0	3.8	8.1	0.7	1.9	4.2	9.6	12.6	22.5	JJA,MAM,SON,DJF	Summer,Spring,Fall,Winter
Australia and Philippines	4.5	10.0	4.8	10.2	6.2	17.1	3.5	8.0	2.0	3.6	DJF,SON,MAM,JJA	Summer,Spring,Fall,Winter
Europe	1.6	3.5	1.1	2.3	0.2	0.6	1.2	2.8	3.8	6.8	JJA,MAM,SON,DJF	Summer,Spring,Fall,Winter
Oceans	5.4	12.0	6.2	13.2	5.9	16.3	7.6	17.4	7.5	13.4	JJA,MAM,SON,DJF	
Land	39.7	88.0	40.6	86.6	30.5	84.0	36.0	82.6	48.4	86.6	JJA,SON,MAM,DJF	
World (<= 37.5)	40.3	89.4	44.1	94.0	35.0	96.4	40.2	92.2	42.5	76.0	*SON,JJA,MAM,DJF*	

and the World Meteorological Organization [WMO, 1953] thunder day statistics. However, the global lightning and thunderstorm frequency are well correlated in phase but not amplitude with the Carnegie curve (not shown here). The combined OTD/LIS diurnal flash rate varies ±35% about the mean, while the Carnegie curve varies around ±15%. A good understanding of this discrepancy remains elusive and will require a more complete theory of storm electrical and lightning behavior across different storm categories and/or lifecycles (e.g., oceanic vs. land-based, active vs. inactive periods) [Williams and Heckman, 1993; Mach et al., 2007]

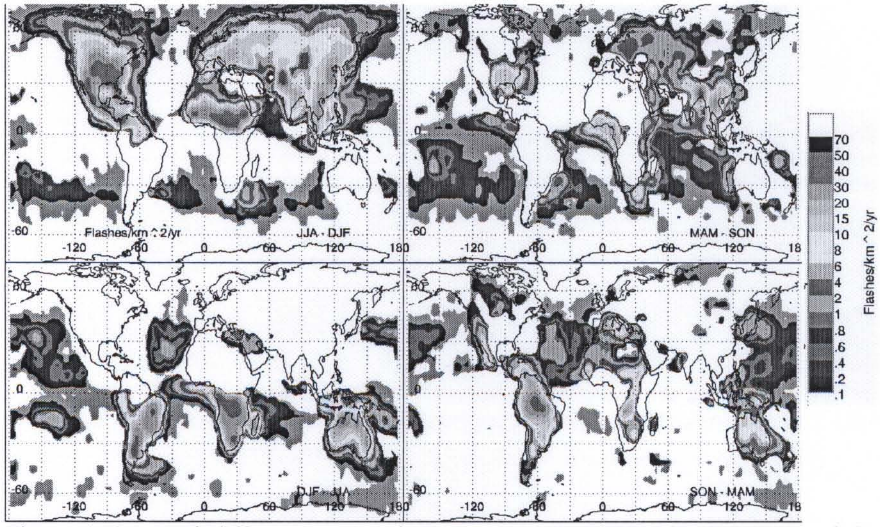

Figure 4. Seasonal difference maps showing positive values of JJA-DJF (top left), DJF-JJA (bottom left), MAM-SON (top right), and SON-MAM (bottom right)

5. SUMMARY

The 11.5-year combined OTD/LIS data sets provide good annual and seasonal diurnal flash rate characterizations. The maximum diurnal flash rate occurs in the Northern Hemisphere summer. Summer lightning dominates over winter activity and springtime lightning dominates over autumn activity at most continental locations. This behavior is reversed over many oceanic locations. In addition, the local time of peak diurnal activity varies as a function of location, shifting toward late evening or early morning hours in regions of the world dominated by large mesoscale convective systems. The global annual diurnal lightning cycle and the Carnegie curve are well correlated in phase but not in amplitude. This discrepancy remains an intriguing unsolved riddle in explaining the global electric circuit.

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